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(54) **FLEXIBLE ELECTRONIC PACKAGE
INTEGRATED HEAT EXCHANGER WITH
COLD PLATE AND RISERS**

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257/E23.104, 693; 165/80.4, 168
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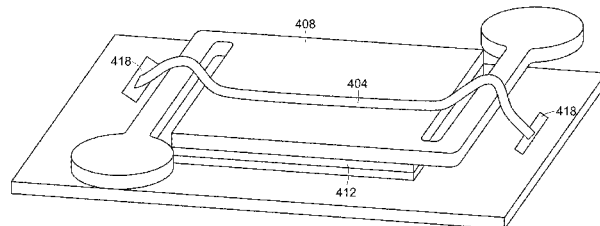
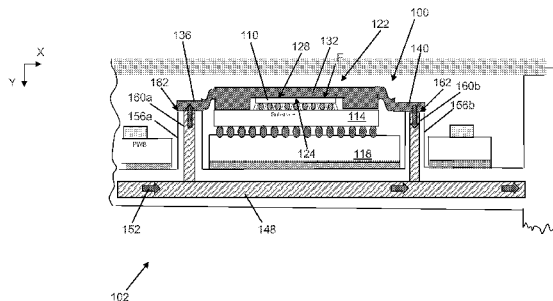
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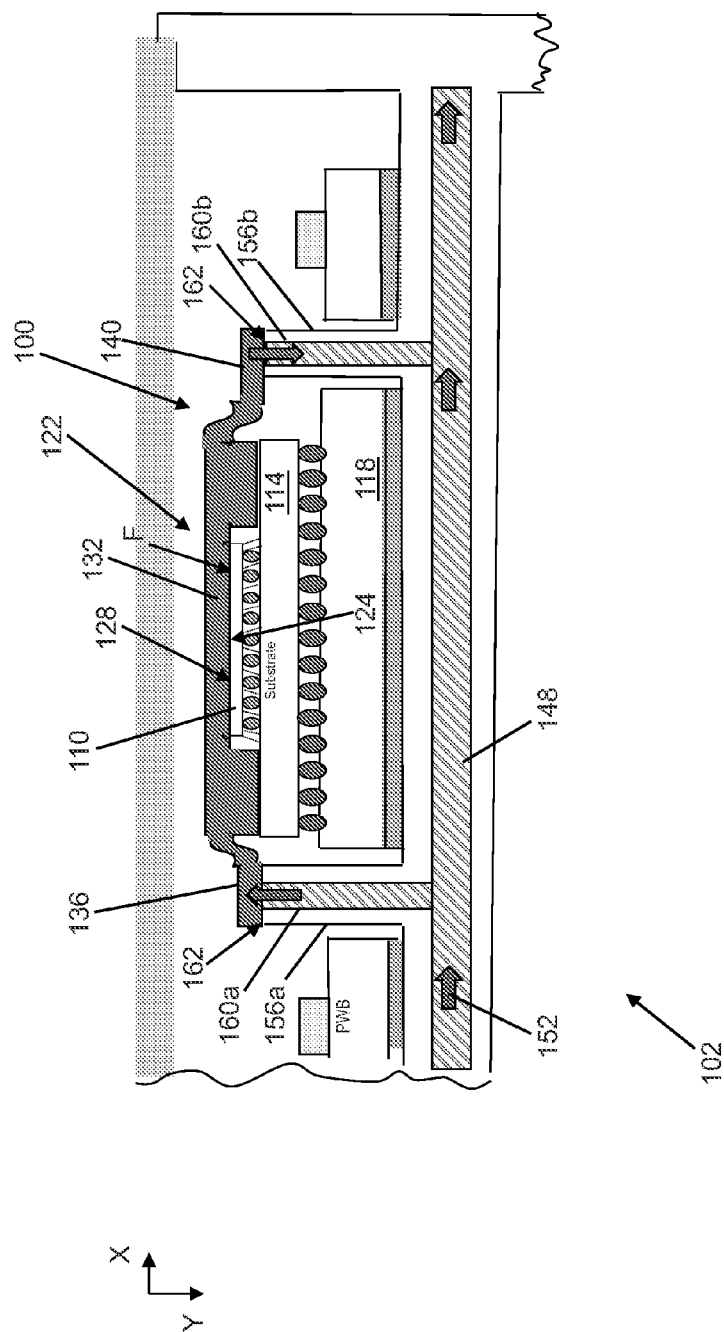
(57) **ABSTRACT**

In some embodiments, a semiconductor cooling apparatus includes a heat exchanger configured to thermally couple to a semiconductor element to transfer heat to coolant flowing through the heat exchanger. The apparatus also includes a flexible coolant supply manifold and a flexible coolant return manifold. The flexible coolant supply manifold and flexible coolant return manifold flex to conform to a height of the semiconductor element to apply a force to maintain the thermal coupling between the heat exchanger and the semiconductor element. The apparatus also includes a cold plate located under the semiconductor element, the cold plate configured to couple to the flexible coolant supply manifold via a first riser to provide coolant to the flexible coolant supply manifold and configured to couple to the flexible coolant return manifold via a second riser to exhaust returned coolant to the cold plate.

16 Claims, 4 Drawing Sheets



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2224/73204 (2013.01); **H01L 2924/15311**
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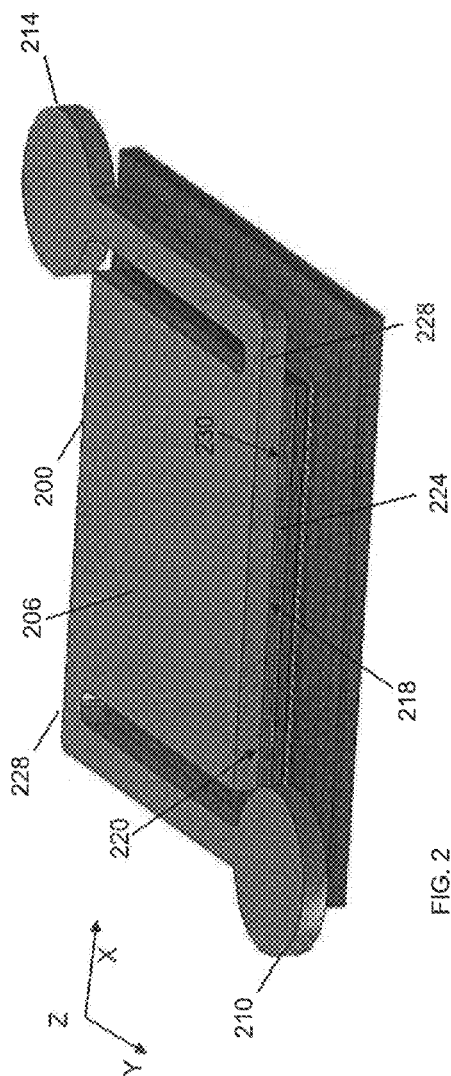


FIG. 2

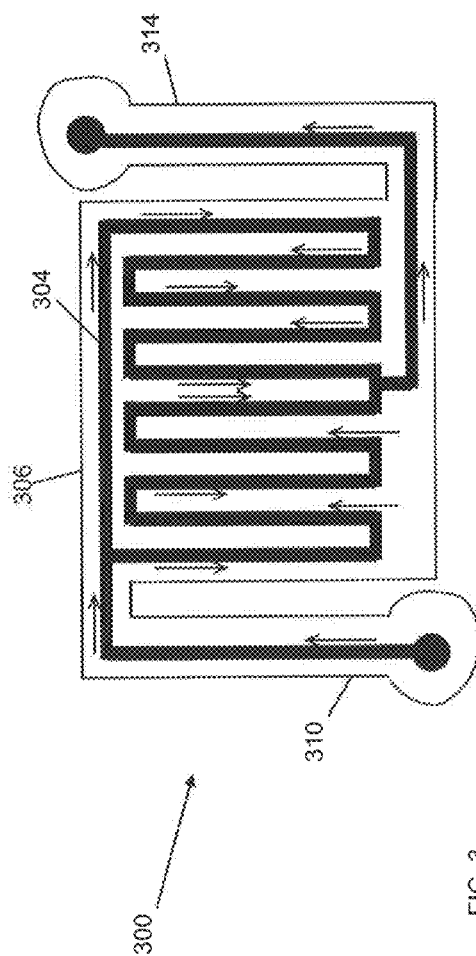


FIG. 3

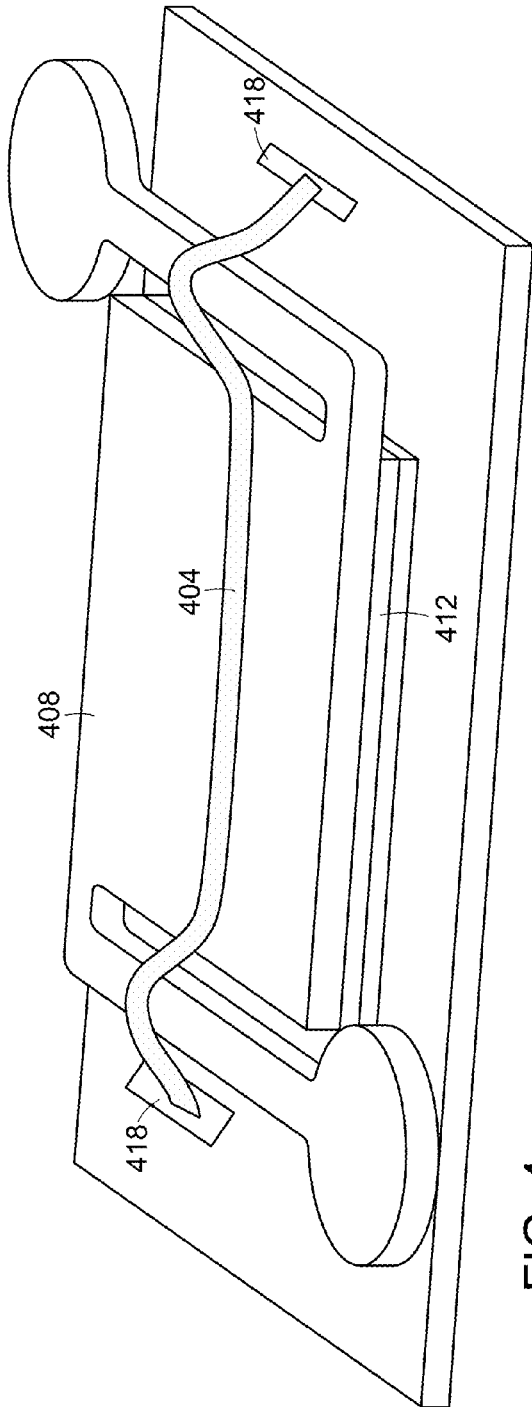


FIG. 4

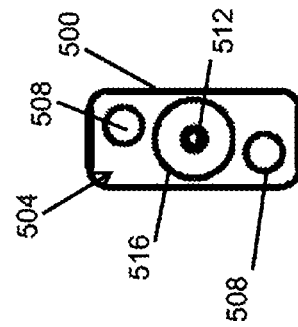
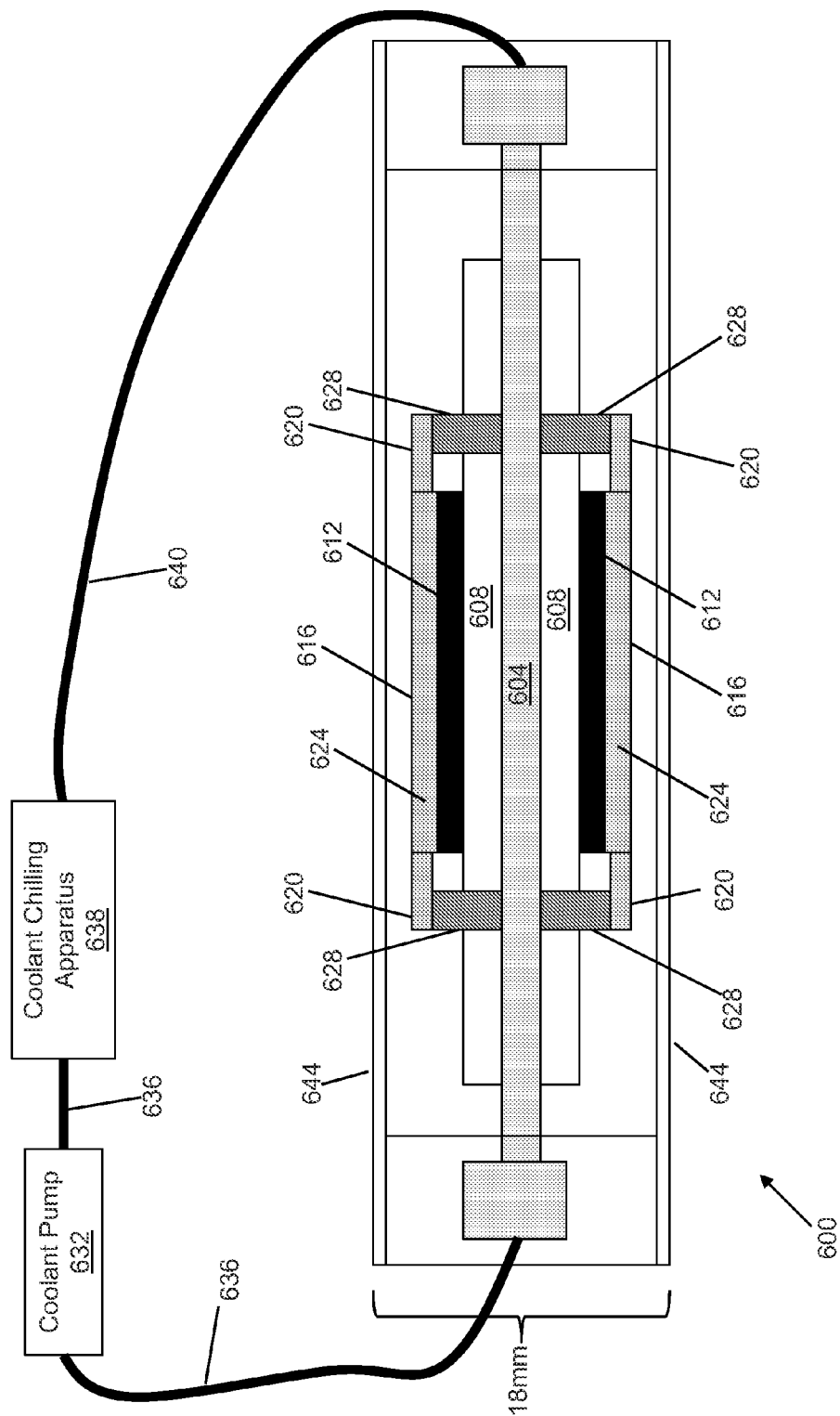


FIG. 5



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FLEXIBLE ELECTRONIC PACKAGE INTEGRATED HEAT EXCHANGER WITH COLD PLATE AND RISERS

RELATED APPLICATIONS

The present application claims priority to U.S. Provisional Patent Application No. 61/619,158, filed Apr. 2, 2012, which is incorporated in its entirety herein by reference.

GOVERNMENT RIGHTS

The invention was supported, in whole or in part, by a grant, Contract No. FA8650-04-G-0002-0001 from the U.S. Air Force. The U.S. Government may have certain rights in the invention.

BACKGROUND

A flat aluminum or copper alloy brazed monolithic cooling apparatus can be used with conformal low thermal performance heat spreaders, such as a gap pad or gap filler material, to accommodate vertical height variations in semiconductors and individual variations in planarity with respect to the cooling apparatus surface. This solution, generally, is effective for low power semiconductors (<10 watts), but, generally, this solution is not effective for semiconductor assemblies with various vertical height variations due to the inefficiency of the heat spreaders and the difficulties of accurately mapping and fitting the custom heat spreaders.

Alternatively, a flat aluminum or copper alloy cooling apparatus can be used with helical or leaf springs and thermal interface materials such as thermal grease to accommodate vertical height variations in semiconductors and individual variations in planarity with respect to the cooling apparatus surface as a datum. This solution, generally, is effective for assemblies with minimal size and weight restrictions, but, generally, this solution is not effective for semiconductor assemblies with size and weight constraints due to the size and rigidity of fluidic interconnects and the springs necessary to enable the vertical height displacement.

Thus, a need exists in the art for a semiconductor cooling apparatus with the features as described herein.

SUMMARY

One approach to a semiconductor cooling apparatus includes a cooling element configured to thermally couple to a semiconductor element. The cooling element includes a heat exchanger configured to thermally couple to the semiconductor element to transfer heat from the semiconductor element to coolant flowing through the heat exchanger. The cooling element also includes a flexible coolant supply manifold coupled to an inlet of the heat exchanger for providing coolant to the heat exchanger and a flexible coolant return manifold coupled to an outlet of the heat exchanger for exhausting returned coolant from the heat exchanger. The flexible coolant supply manifold and flexible coolant return manifold flex to conform to a height of the semiconductor element to apply a force to maintain the thermal coupling between the heat exchanger and the semiconductor element. The cooling apparatus also includes a cold plate configured to couple to the flexible coolant supply manifold via a first riser to provide coolant to the flexible coolant supply manifold and configured to couple to the flexible coolant return manifold via a second riser to exhaust returned coolant to the cold plate. The flexible coolant supply manifold and flexible coolant return manifold flex to conform to a height of at least one of the semiconductor element or risers to apply a force to maintain the thermal coupling between the heat exchanger and the semiconductor element.

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flexible coolant return manifold via a second riser to exhaust returned coolant to the cold plate.

In some embodiments, the first and second risers have internal passages for transporting coolant between the manifolds and cold plate. In some embodiments, the heat exchanger is spring loaded to the semiconductor element by attaching the flexible manifolds to the risers. In some embodiments, the cooling element is deformed at a junction between the heat exchanger and the supply and return manifolds to spring load the heat exchanger to the semiconductor element.

In some embodiments, the heat exchanger is coupled to the semiconductor element as a packaging lid. In some embodiments, the semiconductor cooling apparatus includes a coolant chilling apparatus connected to a coolant supply line and a coolant return line and configured to chill coolant and a coolant pump configured to pump the coolant between the coolant chilling apparatus and cold plate.

In some embodiments, the flexing of the flexible coolant supply manifold and the flexible coolant return manifold reduces a thermal resistance interface between the heat exchanger and the semiconductor element. In some embodiments, the semiconductor cooling apparatus includes a spring clip to couple the heat exchanger and the semiconductor element. In some embodiments, the semiconductor cooling apparatus includes aluminum, copper, stainless steel, titanium, alloys thereof, plastic, semiconductor fabrication materials, or any combination thereof.

In some embodiments, the cold plate is located adjacent to the semiconductor element. In some embodiments, the cold plate is located under the semiconductor element. In some embodiments, the cold plate is located above the flexible coolant supply manifold and flexible coolant return manifold.

Another approach to a semiconductor cooling apparatus includes a cooling element configured to thermally couple to a semiconductor element. The cooling element includes a heat exchanger configured to thermally couple to the semiconductor element to transfer heat from the semiconductor element to coolant flowing through the heat exchanger. The cooling element also includes a flexible coolant supply manifold coupled to an inlet of the heat exchanger for providing coolant to the heat exchanger. The cooling element also includes a flexible coolant return manifold coupled to an outlet of the heat exchanger for exhausting returned coolant from the heat exchanger. The cooling apparatus also includes a cold plate configured to couple to the flexible coolant supply manifold via a first riser to provide coolant to the flexible coolant supply manifold and configured to couple to the flexible coolant return manifold via a second riser to exhaust returned coolant to the cold plate. The flexible coolant supply manifold and flexible coolant return manifold flex to conform to a height of at least one of the semiconductor element or risers to apply a force to maintain the thermal coupling between the heat exchanger and the semiconductor element.

Another approach to a semiconductor cooling apparatus includes a cooling element configured to thermally couple to a semiconductor element. The cooling element includes a heat exchanger configured to thermally couple to the semiconductor element to transfer heat from the semiconductor element to coolant flowing through the heat exchanger. The cooling element also includes a flexible coolant supply manifold coupled to an inlet of the heat exchanger for providing coolant to the heat exchanger. The cooling element also includes a flexible coolant return manifold coupled to an outlet of the heat exchanger for exhausting

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returned coolant from the heat exchanger. The flexible coolant supply manifold and flexible coolant return manifold flex to conform to a height of the semiconductor element to apply a force to maintain the thermal coupling between the heat exchanger and the semiconductor element. The cooling apparatus also includes a cold plate configured to couple to the flexible coolant supply manifold to provide coolant to the flexible coolant supply manifold and configured to couple to the flexible coolant return manifold to exhaust returned coolant to the cold plate.

Another approach to a cooling apparatus includes a cooling element configured to thermally couple to an object. The cooling element includes a heat exchanger configured to thermally couple to the object to transfer heat from the object to coolant flowing through the heat exchanger. The cooling element also includes a flexible coolant supply manifold coupled to an inlet of the heat exchanger for providing coolant to the heat exchanger. The cooling element also includes a flexible coolant return manifold coupled to an outlet of the heat exchanger for exhausting returned coolant from the heat exchanger. The flexible coolant supply manifold and flexible coolant return manifold flex to conform to a height of the object to apply a force to maintain the thermal coupling between the heat exchanger and the object. The cooling apparatus also includes a cold plate configured to couple to the flexible coolant supply manifold via a first riser to provide coolant to the flexible coolant supply manifold and configured to couple to the flexible coolant return manifold via a second riser to exhaust returned coolant to the cold plate.

The cooling methods and systems described herein (hereinafter "technology") can provide one or more of the following advantages. One advantage of the technology is that the flexibility in the cooling apparatus advantageously increases the heat transfer between the semiconductor element and the cooling apparatus, thereby extending the life of the semiconductor element by promoting proper cooling of the semiconductor element. The flexibility of the cooling apparatus advantageously reduces the installation time and cost by removing any needed individual customizations due to, for example, differences in height of semiconductor elements or mechanical assembly tolerances, thereby decreasing the overall cost of the devices associated with the semiconductor element while increasing the heat transfer. The monolithic construction of the semiconductor cooling apparatus allows for installation in volume, weight, and height constrained applications.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages will be apparent from the following more particular description of the embodiments, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the embodiments.

FIG. 1 is a schematic illustration of an exemplary semiconductor cooling apparatus.

FIG. 2 is a schematic illustration of an exemplary cooling element of a semiconductor cooling apparatus.

FIG. 3 is a schematic illustration of internal flow passages of an exemplary cooling element.

FIG. 4 is a schematic illustration of an exemplary fastener mounting a cooling element to a semiconductor element.

FIG. 5 is a schematic illustration of a mounting arrangement for an exemplary cooling element.

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FIG. 6 is a schematic illustration of an electronics assembly incorporating a cooling apparatus, according to an illustrative embodiment.

DETAILED DESCRIPTION

Semiconductor elements, such as a ball grid array (BGA), can be used as part of aerospace sensor architectures and/or other semiconductor architectures. In most instances, each of the semiconductor elements is soldered to a primary circuit board (e.g., motherboard, array, etc.) creating a semiconductor array. Due to the size, spacing, and thermal properties of the semiconductor elements on the array, a semiconductor cooling apparatus is needed to quickly and efficiently transfer heat from each element. However, elements in the semiconductor array can vary in height due to manufacturing tolerances, making it difficult to effectively and consistently transfer heat from the semiconductor elements. It is also difficult to integrate coolant supply mechanisms into a semiconductor cooling apparatus because of the difficulty in routing coolant to a cooling element while maintaining a low profile and/or compact electronics system that incorporates the semiconductor element and cooling apparatus. Thus, the semiconductor cooling apparatus, as described herein, includes a flexible cooling element to thermally couple to a semiconductor element. The semiconductor cooling apparatus also includes a cold plate that effectively routes coolant to the cooling element and exhausts heated coolant received from the cooling element.

Advantageously, the monolithic cooling element can flex to conform to the height of a semiconductor element (e.g., a math coprocessor is 0.02 inches high and a video processor is 0.04 inches high, BGA applications are about 0.08 inches to about 0.14 inches, an input/output processor is 0.023 inches high and an encryption processor is 0.034 inches high, etc.), thereby increasing the thermal transfer between a semiconductor element and a cooling element. Each cooling element is able to cool a single component with height variations due to manufacturing tolerances. For example, BGA uses solder balls between the package and the board for passing electrical signals; the solder balls are melted when the BGA is installed. Every time a BGA is installed, that solder thickness varies. The cooling elements described mitigate height variations of the same part from unit to unit. The monolithic cooling elements described advantageously integrate a heat exchanger and flexible supply and return manifolds into a single component. Having a monolithic element eliminates the need for another fluidic interconnect to transfer the coolant from the heat exchanger to the flexible manifolds. Those fluidic interconnects are leaky and bulky. In some examples, a cooling element is formed through a bonding process to form the monolithic structure. In other examples, the bonding includes diffusion bonding, adhesive bonding, brazing, and/or any other type of bonding mechanism.

Effective cooling of semiconductor elements presents a unique thermal design problem due to variations in the physical dimensions of the semiconductor elements from one assembly to the next assembly and/or between production units. The semiconductor cooling apparatus as described herein can advantageously solve this thermal design problem by combining flexible cooling elements with coolant supply features that integrate both structural and hydraulic functions. The architecture of the semiconductor cooling apparatus (e.g., copper foil, copper alloy, etc.) can be thin enough to be strategically deformed along the coolant manifolds (e.g., coolant supply manifold, coolant return

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manifold, etc.) to enable each cooling element to flex independently for a respective semiconductor element.

FIG. 1 is a schematic illustration of an exemplary semiconductor cooling apparatus **100** for a semiconductor element **110** coupled to a substrate **114** in an electronics assembly **102**. The substrate **114** is below the semiconductor element **110**. The substrate is coupled to a printed wiring board (PWB) **118** below the substrate **114** (e.g., a ball grid array (BGA), computer motherboard, etc.). The semiconductor cooling apparatus **100** includes a flexible cooling element **122** that has a cooling surface **124** that is thermally coupled to (e.g., in thermal contact with) a surface **128** of the semiconductor element **110**.

The flexibility of the cooling element **122** advantageously increases the heat transfer between the semiconductor element **110** and the cooling element **122**, thereby extending the life of the semiconductor element **110** by promoting proper cooling of the semiconductor element **110**. The flexibility of the cooling element **122** and/or design of the semiconductor cooling apparatus advantageously reduce the installation time and cost by removing any needed individual customization, thereby decreasing the overall cost of the devices associated with the semiconductor element **110** while increasing the heat transfer. The cooling elements described herein provide for improved thermal performance with minimal intrusion into the design and assembly in the form of weight, size, support hardware (e.g., plumbing hoses), reliable leak-free coolant interconnect simplicity.

The cooling element **122** includes a heat exchanger **132**, a flexible coolant supply manifold **136**, and a flexible coolant return manifold **140**. In this embodiment, the heat exchanger is coupled to the semiconductor element **110** as a packaging lid (to, for example, encapsulate or otherwise house of protect the semiconductor element **110**). The cooling element **122** can be attached to the semiconductor element **110** when the other components (e.g., substrate cold plate, risers) are assembled. Or, in some embodiments, the cooling element **122** is attached to the combination of the substrate **114** and the semiconductor element **110** at the facility where the semiconductor element **122** is fabricated; the combination is then delivered for final assembly.

The cooling apparatus **100** also includes a cold plate **148** located below the printed wiring board **118**. Coolant **152** flows through the cold plate **148**. The cooling apparatus **100** also includes two or more risers **156a** and **156b** (generally **156**) that deliver coolant **152** to the cooling element **122** and exhaust returned coolant **152** from the cooling element **122**. Riser **156a** is coupled to the cold plate **148** and delivers chilled coolant to the flexible coolant supply manifold **136** via an internal passage **160a** of the riser **156a**. The flexible coolant supply manifold **136** delivers the coolant to the heat exchanger **132** and the heat exchanger **132** transfers heat from the semiconductor element **110** to the coolant flowing in the heat exchanger **132**. The heated coolant is then exhausted from the heat exchanger **132** to the flexible coolant return manifold **140**. The flexible coolant return manifold **140** then provides the returned coolant to the cold plate **148** via the internal passage **160b** of the riser **156b**. The exhausted coolant is then pumped to a coolant chilling apparatus (not shown) by a coolant pump (not shown) to chill the coolant. In some embodiments, the cooling apparatus **102** does not have risers **156a** and **156b**. The flexible coolant supply manifold **136** is coupled to the cold plate **148** and receives coolant from the cold plate **148**. The flexible coolant return manifold **140** is coupled to the cold plate **148** to exhaust the heated coolant to the cold plate **148**.

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In some examples, the coolant includes single phase or two-phase coolants (e.g., where the liquid coolant evaporates in the heat exchanger). In some examples, the coolant includes single phase liquids (e.g., polyalphaolefin (PAO), Coolanol, water, glycol water mixtures (EGW, PGW), fuels (JP-5, JP-8)) and/or two-phase coolants (water, ammonia, methanol, Fluorinert, glycol water mixtures (EGW, PGW)).

In this embodiment, the cold plate **148** is located below the printed wiring board **118**. However, in some embodiments, the cold plate **148** is not located below the printed wiring board **118**. The cold plate **148** could be located above or next to/adjacent the printed wiring board **118**. For example, in one embodiment, the system includes a 6-sided box where the printed wiring board is bonded to the base of the box which is solid metal, and coolant runs through one or more side walls of the box. The flexible manifolds are bent 90-degrees to couple to the cold plate, or, risers extend out from the side of the box to enable fluidic and mechanical coupling to accomplish the principles described herein.

Referring to FIG. 1, the risers **156** can be, for example, posts or other structures extending from a surface of the cold plate **148**. The risers **156** can be, for example, bonded to the cold plate **148**. The flexible coolant supply manifold **136** and the flexible coolant return manifold **140** can be attached to the risers **156** by screws (as described further below) or otherwise coupled (e.g., by adhesive bonding, diffusion bonding) to the risers **156** by one or more alternative connection methods. The risers **156** can be manufactured using the same material as the cold plate **148**, or other suitable material (e.g., plastic, rubber, metal, metal alloy) that allows for coolant to be transmitted through the risers **156**.

The heat exchanger **132** can be spring loaded to the semiconductor element **110** if the top surface **162** of the risers **156** is lower (in the positive direction of the Y-axis) than the top surface **128** of the semiconductor element **110**. By attaching the flexible manifolds **136** and **140** to the risers, the heat exchanger **132** is deformed along the length of the supply and return manifolds **136** and **140**. The deformation causes the cooling element **122** to be spring loaded to the semiconductor element **110** thereby applying a force to maintain the thermal coupling between the heat exchanger **132** and the semiconductor element **110**. The force generated can be varied based on one or more of a variety of design parameters. The size and rigidity of the coolant supply and return elements and interconnects can be varied to define or alter the flexibility of the manifolds and the forces generated. If the deformation of a runner is elastic, the force is a function of the spring constant of the flexible manifolds and the displacement of the flexible manifolds (in accordance with $F=kx$, where F is the force, k is the spring constant, and x is the displacement). The spring constant can be changed or specified based on, for example, the material type of the flexible manifold, the wall thickness of the of the cooling element where the flexible manifolds are deformed, or another geometric property of the flexible manifold (e.g., length, width, thickness). In some embodiments, the runners **512** may be designed for plastic deformation instead of elastic deformation.

In some examples, the heat exchanger is fixed in space and the flexible manifolds flex to mate with the risers. In some embodiments, the flexible manifolds flex to enable the heat exchanger to mate with the semiconductor element. In some examples, the flexible properties of the cooling element **122** reduce a thermal interface resistance between the cooling element **122** and the semiconductor element **110**. For example, the cooling element **122** flexes 0.030 inches to

be in contact with the semiconductor element **122**. The flexibility of the cooling element **122** advantageously enables the thermal resistance interface to be reduced (e.g., reduced thermal penalty from 20° C. to 10° C.; reduced thermal penalty from 8° C. to 3.2° C., etc.), thereby increasing the efficiency of the semiconductor cooling apparatus **100** and increasing the life of the semiconductor element **110**.

In some examples, the semiconductor cooling apparatus (or portions of it) can be produced using aluminum, copper, stainless steel, titanium, alloys thereof, and/or material with high heat transfer (e.g., Glidcop® available from SCM Metal Products, Inc., a copper alloy, etc.). In some examples, the semiconductor cooling apparatus can be produced using plastic material or semiconductor fabrication materials (e.g., silicon).

The disclosed semiconductor cooling apparatus includes a monolithic cooling element configured to thermally couple to a semiconductor element. The monolithic cooling element includes a heat exchanger portion, a flexible coolant supply manifold and a flexible coolant return manifold. The heat exchanger portion is configured to thermally couple to the semiconductor element to transfer heat from the semiconductor element to coolant flowing through the heat exchanger portion. The heat exchanger portion includes a planar structure and a plurality of internal coolant paths extending through the planar structure between an inlet coolant path of the planar structure and an outlet coolant path of the planar structure.

The flexible coolant supply manifold is coupled to an inlet of the heat exchanger portion for providing coolant to the heat exchanger portion. Referring to FIG. 2, the flexible coolant supply manifold includes a first flexible arm portion **211** of the monolithic cooling element. The first flexible arm **211** portion includes a proximal end attached to the planar structure, a distal end separated by a first gap from the planar structure, and an internal inlet path. The internal inlet path extends from the distal end of the first flexible arm portion **211** to the proximal end of the first flexible arm portion **211** and is coupled to the inlet coolant path of the planar structure.

Similarly, the flexible coolant return manifold is coupled to an outlet of the heat exchanger portion for providing coolant to the heat exchanger portion. The flexible coolant return manifold includes a second flexible arm portion **215** of the monolithic cooling element. The second flexible arm portion **215** includes a proximal end attached to the planar structure, a distal end separated by a second gap from the planar structure, and an internal inlet path. The internal inlet path extends from the distal end of the second flexible arm portion **215** to the proximal end of the second flexible arm portion **215** and is coupled to the outlet coolant path of the planar structure.

Some embodiments of the semiconductor cooling apparatus also include a first riser coupled to a cold plate and attached to the distal end of the first flexible arm portion **211** and a second riser coupled to the cold plate and attached to the distal end of the second flexible arm portion **215**. The first riser includes an internal fluid path between the cold plate and the distal end of the first flexible arm portion **211** and the second riser includes an internal fluid path between the cold plate and the distal end of the second flexible arm portion **215**. In this example, a first deformed portion of the first flexible arm portion **211** conforms to a first height difference between the heat exchanger portion and the first riser, and a second deformed portion of the second flexible

arm portion **215** conforms to a second height difference between the heat exchanger portion and the second riser.

FIG. 2 is a schematic illustration of an exemplary cooling element **200** of a semiconductor cooling apparatus (e.g., the cooling element **122** of FIG. 1). The cooling element **200** includes a heat exchanger **206**, a flexible coolant supply manifold **210** and a coolant return manifold **214**. The coolant supply manifold **210** and the coolant return manifold **214** are coupled to the heat exchanger **206** at junction **228**. The coolant supply manifold **210** and the coolant return manifold **214** flex independent of the heat exchanger **206** along the length of the manifold. As illustrated in FIG. 2, the wrapping-around (in the X-Y plane) the coolant supply manifold **210** and the coolant return manifold **214** around the heat exchanger **206** advantageously enables the cooling element **200** to flex and pivot in 3-dimensions (i.e., along the X, Y and Z axes). The bottom surface **218** of the heat exchanger **206** is thermally coupled to the top surface **230** of the semiconductor element **224**.

FIG. 3 is a schematic illustration of internal flow passages **304** of an exemplary cooling element **300** (e.g., the cooling element **200** of FIG. 2). The cooling element **300** has a flexible coolant supply manifold **310**, a coolant return manifold **314**, and a heat exchanger **306**. An internal flow passage **304** of the flexible coolant supply manifold **310** provides coolant to the internal flow passages **304** of the heat exchanger **306**. The coolant flows through the passages **304** of the heat exchanger **306** as illustrated by the arrows. Alternate numbers, sizes, and configurations of the passages can be used in different embodiments. For example, the number of passages **304** can be increased, and the spacing between passages can be decreased in some embodiments to cover a larger percentage of the total area of the heat exchanger **306** to increase the thermal exchange efficiency of the heat exchanger **306**.

FIG. 4 is a perspective view of an exemplary fastener **404** coupling a cooling element **408** to a semiconductor element **412**, according to an illustrative embodiment. In this embodiment, the fastener **404** is a spring clip that clips into two slots **418** on opposing sides of the cooling element **408**. In some embodiments, the slots are located (e.g., formed or machined) in a cold plate (e.g., the cold plate **148** of FIG. 1) below the semiconductor element **412**.

FIG. 5 is a schematic illustration of a mounting arrangement on a top surface **504** of a riser **500** of a cooling apparatus for an exemplary cooling element (e.g., top surface **162** of riser **156a** of FIG. 1). The riser **500** includes two corner holes **508** that are threaded to accept screws. The riser **500** also includes a center hole **512** that provides access to the internal passage in the riser **500** (e.g., internal passage **160a** of the riser **156a** of FIG. 1). An o-ring **516** is located around the center hole **512** to provide a fluid seal between a flexible coolant manifold and the riser **500** when the flexible coolant manifold is coupled to the top surface **504** surface of the riser **500**.

FIG. 6 is a schematic cross-sectional view of an exemplary electronics assembly **600** that incorporates a cooling apparatus, according to an illustrative embodiment. The compact packaging afforded by the principles described advantageously allows for the assembly to be compact with a relatively low profile (e.g., 18 mm in this embodiment). The cooling apparatus includes a cold plate **604** located between two printed wire boards **608**. A semiconductor element **612** is mounted to each printed wire board **608**. The cooling apparatus also includes two cooling elements **616** (e.g., cooling element **200** of FIG. 2); one cooling element **616** is coupled to each of the semiconductor elements **612**.

The heat exchanger **624** of the cooling element **616** is thermally coupled to each of the semiconductor elements **612**. The supply and return cooling manifolds **620** of the cooling elements **616** are coupled to the risers **628**, similarly as described with respect to the manifolds **136** and **140**, and risers **156** of FIG. 1. The risers **628** are coupled to the cold plate **604**. Coolant flowing through the cold plate **604** is delivered to the cooling elements and exhausted from the cooling elements via internal passages in the risers. The assembly includes two covers **644** that enclose the cold plate **604**, printed wire boards **608**, semiconductor elements **612**, cooling elements **616**, and the risers **628**.

The cooling apparatus includes a coolant chilling apparatus **638** coupled to one or more coolant supply lines **636** and one or more coolant return lines **640**. The coolant chilling apparatus **638** is configured to chill coolant. The cooling apparatus includes a coolant pump **632** that is configured to pump the coolant through the supply lines and various coolant passages in the cooling apparatus. The pump **632** pumps chilled coolant through the coolant supply line **636** which is directed to an input of the cold plate **604**.

Comprise, include, and/or plural forms of each are open ended and include the listed parts and can include additional parts that are not listed. And/or is open ended and includes one or more of the listed parts and combinations of the listed parts.

One skilled in the art will realize the invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments are therefore to be considered in all respects illustrative rather than limiting of the invention described herein. Scope of the invention is thus indicated by the appended claims, rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein. In addition, the figures and foregoing descriptions identify a semiconductor to be thermally coupled to the heat exchanger, but the art described herein is not limited to semiconductors and can apply to any object which requires temperature control through heat rejection or addition.

What is claimed is:

1. A semiconductor cooling apparatus, comprising:

a monolithic cooling element configured to thermally couple to a semiconductor element, wherein the monolithic cooling element comprises:

a heat exchanger portion configured to thermally couple to the semiconductor element to transfer heat from the semiconductor element to coolant flowing through the heat exchanger portion, the heat exchanger portion comprising a planar structure and a plurality of internal coolant paths extending through the planar structure between an inlet coolant path of the planar structure and an outlet coolant path of the planar structure;

a flexible coolant supply manifold coupled to an inlet of the heat exchanger portion for providing coolant to the heat exchanger portion, the flexible coolant supply manifold comprising a first flexible arm portion of the monolithic cooling element, the first flexible arm portion comprising a proximal end attached to the planar structure, a distal end separated by a first gap from the planar structure, and an internal inlet path, the internal inlet path extending from the distal end of the first flexible arm portion to the proximal end of the first flexible arm portion and coupled to the inlet coolant path of the planar structure;

a flexible coolant return manifold coupled to an outlet of the heat exchanger portion for providing coolant to the heat exchanger portion, the flexible coolant return manifold comprising a second flexible arm portion of the monolithic cooling element, the second flexible arm portion comprising a proximal end attached to the planar structure, a distal end separated by a second gap from the planar structure, and an internal inlet path, the internal inlet path extending from the distal end of the second flexible arm portion to the proximal end of the second flexible arm portion and coupled to the outlet coolant path of the planar structure,

and

a first riser coupled to a cold plate and attached to the distal end of the first flexible arm, the first riser comprising an internal fluid path between the cold plate and the distal end of the first flexible arm;

a first deformed portion of the first flexible arm conforming to a first height difference between the heat exchanger portion and the first riser; and

a second riser coupled to the cold plate and attached to the distal end of the second flexible arm, the second riser comprising an internal fluid path between the cold plate and the distal end of the second flexible arm; and

a second deformed portion of the second flexible arm conforming to a second height difference between the heat exchanger portion and the second riser.

2. The semiconductor cooling apparatus of claim 1, wherein the heat exchanger portion is spring loaded to the semiconductor element by attaching the flexible manifolds to the risers.

3. The semiconductor cooling apparatus of claim 1, comprising:

a first deformation of the monolithic cooling element at a junction of the heat exchanger portion to the supply manifold and a second deformation of the monolithic cooling element at a junction of the heat exchanger portion to the return manifold, wherein the first deformation and the second deformation apply a spring load between the heat exchanger portion and the semiconductor element.

4. The semiconductor cooling apparatus of claim 1, wherein the heat exchanger portion is coupled to the semiconductor element as a packaging lid.

5. The semiconductor cooling apparatus of claim 1, comprising:

a coolant chilling apparatus connected to a coolant supply line and a coolant return line and configured to chill coolant; and

a coolant pump configured to pump the coolant between the coolant chilling apparatus and the cold plate.

6. The semiconductor cooling apparatus of claim 1, further comprising a spring clip coupling the heat exchanger and the semiconductor element.

7. The semiconductor cooling apparatus of claim 1, wherein the semiconductor cooling apparatus comprises aluminum, copper, stainless steel, titanium, alloys thereof, plastic, semiconductor fabrication materials, or a combination thereof.

8. The semiconductor cooling apparatus of claim 1, wherein the cold plate is located adjacent to the semiconductor element.

9. The semiconductor cooling apparatus of claim 1, wherein the cold plate is located under the semiconductor element.

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10. The semiconductor cooling apparatus of claim 1, wherein the cold plate is located above the flexible coolant supply manifold and flexible coolant return manifold.

11. The semiconductor cooling apparatus of claim 1, wherein the flexible coolant supply manifold and flexible coolant return manifold are flexed to conform to a height of one of a plurality of semiconductor elements or risers and apply a force that maintains the thermal coupling between the heat exchanger and the semiconductor element.

12. A semiconductor cooling apparatus, comprising:

a monolithic cooling element configured to thermally couple to a semiconductor element, wherein the monolithic cooling element comprises:

a heat exchanger portion configured to thermally couple to the semiconductor element to transfer heat from the semiconductor element to coolant flowing through the heat exchanger portion, the heat exchanger portion comprising a planar structure and a plurality of internal coolant paths extending through the planar structure between an inlet coolant path of the planar structure and an outlet coolant path of the planar structure;

a flexible coolant supply manifold coupled to an inlet of the heat exchanger portion for providing coolant to the heat exchanger portion, the flexible coolant supply manifold comprising a first flexible arm portion of the monolithic cooling element, the first flexible arm portion comprising a proximal end attached to the planar structure, a distal end separated by a first gap from the planar structure, and an internal inlet path, the internal inlet path extending from the distal end of the first flexible arm portion to the proximal end of the first flexible arm portion and coupled to the inlet coolant path of the planar structure;

a flexible coolant return manifold coupled to an outlet of the heat exchanger portion for providing coolant to the heat exchanger portion, the flexible coolant return manifold comprising a second flexible arm portion of the monolithic cooling element, the second flexible arm portion comprising a proximal end attached to the planar structure, a distal end separated by a second gap from the planar structure, and an internal inlet path, the internal inlet path extending from the distal end of the second flexible arm portion to the proximal end of the second flexible arm portion and coupled to the outlet coolant path of the planar structure,

wherein the flexible coolant supply manifold and flexible coolant return manifold are flexed to conform to a height of the semiconductor element and apply a force that maintains the thermal coupling between the heat exchanger and the semiconductor element; and

a cold plate configured to couple to the flexible coolant supply manifold to provide coolant to the flexible coolant supply manifold and configured to couple to the flexible coolant return manifold to exhaust returned coolant to the cold plate.

13. A cooling apparatus, comprising:

a monolithic cooling element configured to thermally couple to a semiconductor element, wherein the monolithic cooling element comprises:

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a heat exchanger portion configured to thermally couple to the semiconductor element to transfer heat from the semiconductor element to coolant flowing through the heat exchanger portion, the heat exchanger portion comprising a planar structure and a plurality of internal coolant paths extending through the planar structure between an inlet coolant path of the planar structure and an outlet coolant path of the planar structure;

a flexible coolant supply manifold coupled to an inlet of the heat exchanger portion for providing coolant to the heat exchanger portion, the flexible coolant supply manifold comprising a first flexible arm portion of the monolithic cooling element, the first flexible arm portion comprising a proximal end attached to the planar structure, a distal end separated by a first gap from the planar structure, and an internal inlet path, the internal inlet path extending from the distal end of the first flexible arm portion to the proximal end of the first flexible arm portion and coupled to the inlet coolant path of the planar structure;

a flexible coolant return manifold coupled to an outlet of the heat exchanger portion for providing coolant to the heat exchanger portion, the flexible coolant return manifold comprising a second flexible arm portion of the monolithic cooling element, the second flexible arm portion comprising a proximal end attached to the planar structure, a distal end separated by a second gap from the planar structure, and an internal inlet path, the internal inlet path extending from the distal end of the second flexible arm portion to the proximal end of the second flexible arm portion and coupled to the outlet coolant path of the planar structure,

wherein the flexible coolant supply manifold and flexible coolant return manifold are flexed to conform to a height of the semiconductor element and apply a force that maintains the thermal coupling between the heat exchanger and the semiconductor element; and

a cold plate configured to couple to the flexible coolant supply manifold via a first riser to provide coolant to the flexible coolant supply manifold and configured to couple to the flexible coolant return manifold via a second riser to exhaust returned coolant to the cold plate.

14. The semiconductor cooling apparatus of claim 1, wherein the flexible coolant supply manifold and flexible coolant return manifold are in-plane with the heat exchanger portion.

15. The semiconductor cooling apparatus of claim 1, wherein the flexible coolant supply manifold and flexible coolant return manifold mechanically couple the heat exchanger portion to the cold plate.

16. The semiconductor cooling apparatus of claim 1, wherein a first spring force caused by flexing of the coolant supply manifold and a second spring force caused by flexing of the flexible coolant return manifold engage the heat exchanger portion to the semiconductor element.

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